DID LAKE MANLY OVERFLOW AT ASH HILL?

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Received 9 September 1996; Revised 14 April 1997; Accepted 15 September 1997

ABSTRACT

Near Ash Hill in the Mojave Desert, California, there is an impressive channel that is cut in bedrock. The channel is in a pass through which Lake Manly, the pluvial lake that occupied Death Valley, could have overflowed. Indeed, the channel has been attributed to such overflow. The pass, however, is 500 m above the highest shorelines of Lake Manly in Death Valley, and evidence from cores from dry lakes on either side of the pass does not support the overflow hypothesis.

Despite its size, new field observations suggest that the channel was actually eroded by local runoff. Water from several tributaries collects into a single channel at this point, and the resulting discharge is apparently sufficient to cause retreat of a knickpoint from the downstream edge of the basalt flow into which the channel is cut.

Earth surf. process. landforms, **23,** 377–384 (1998)
KEY WORDS: Lake Manly; Death Valley; California; pluvial lakes

INTRODUCTION

Pluvial lakes occupied closed basins in the western United States repeatedly during the Pleistocene. The largest of these were lakes Lahontan and Bonneville (Gilbert, 1890; Morrison, 1964; Benson *et al*., 1990; Reheis, 1996) (Figure 1). Although much smaller, Lake Manly in Death Valley (Blackwelder, 1933, 1954; Hooke, 1972; Hooke and Dorn, 1992; Li *et al*., 1996; Roberts, 1996) still had a surface area of over 3000 km^2 during its highest stands.

The climate during these pluvial periods must have differed considerably from the present one. More significantly, emerging evidence (Hooke and Dorn, 1992) suggests that the penultimate pluvial period, at least in Death Valley, began earlier than the corresponding (Stage 6) glacial period as defined by the deep-sea oxygen isotope record. This is consistent with data from North Africa (Rossignol-Strick, 1985).

The principal measures of climate are, of course, precipitation and temperature. In closed basins, neglecting changes in groundwater storage, the input of water from precipitation equals losses by evaporation from the soil and from lake surfaces. Evaporation from lake surfaces scales with the surface area (as well as temperature). Thus, estimates of surface areas of lakes are required for reconstructions of pluvial climates.

The observations discussed in this paper concern the maximum area of Lake Manly, and in particular the question of whether it ever became large enough to overflow at a place called Ash Hill (Figure 1). If it did overflow, its surface area may have been as large as 6500 km^2 (Hale, 1985, p. 64). If it did not overflow, it may never have been larger than 3500 km^2, its probable size early in oxygen isotope Stage 6 time (Hooke, 1996).

Ash Hill derives its name from the fact that it is a high point on the Santa Fe Railroad line to Los Angeles. Topographically, however, Ash Hill is a saddle or pass, not a hill. It is at an elevation of 595 m above sea level.

About 3 km downflow from Ash Hill pass there is a channel cut in basalt (Figure 2). The channel lies at the toe of an alluvial fan, the Ash Hill fan (Figure 3). Hale (1984, 1985) has argued that this channel was cut by water overflowing from Lake Manly through Ash Hill pass. The reach of the channel that he studied most intensively (Figure 2) is 9 m deep and its central section is over 35 m wide. These dimensions make it difficult to believe that it was cut by flows from the *c*. 16 km^2 area that used to drain to it before an avulsion in the fairly

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CCC 0197-9337/98/040377–08 $17.50

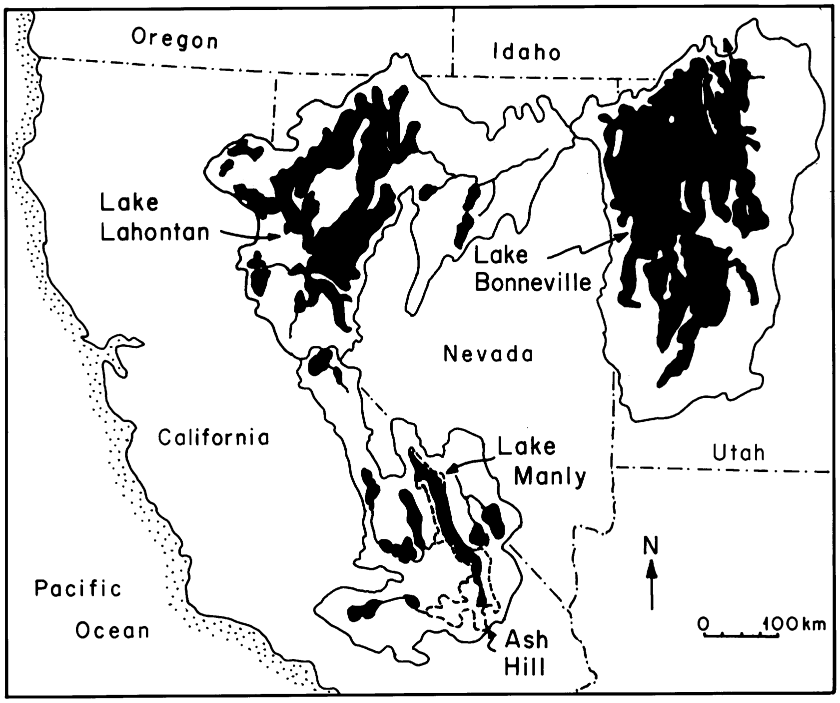

Figure 1. Map of major pluvial lakes in the western United States showing relation between Death Valley and the pass at Ash Hill. Maximum size of Lake Manly as envisaged by Hooke (unpublished) (solid black) and by Hale (1985) (dashed line) is shown. (Modified from Hale, 1985, plate 1)

Figure 2. Photograph of the straight reach of Ash Hill channel; view is upstream. In the distance, the channel bends sharply to the right and then back to the left

distant past that reduced the drainage area (Figure 3). Ash Hill pass, however, is over 500 m above the highest prominent shorelines in Death Valley (Hooke, 1972). Furthermore, cores from Bristol Lake, which lies downstream from the pass, do not contain sediments that would be consistent with a freshwater phase of the lake in the last *c*. 4 ma (Rosen, 1991; Brown and Rosen, 1995, p. 290). Nor do cores from Soda Lake (Muessig *et*

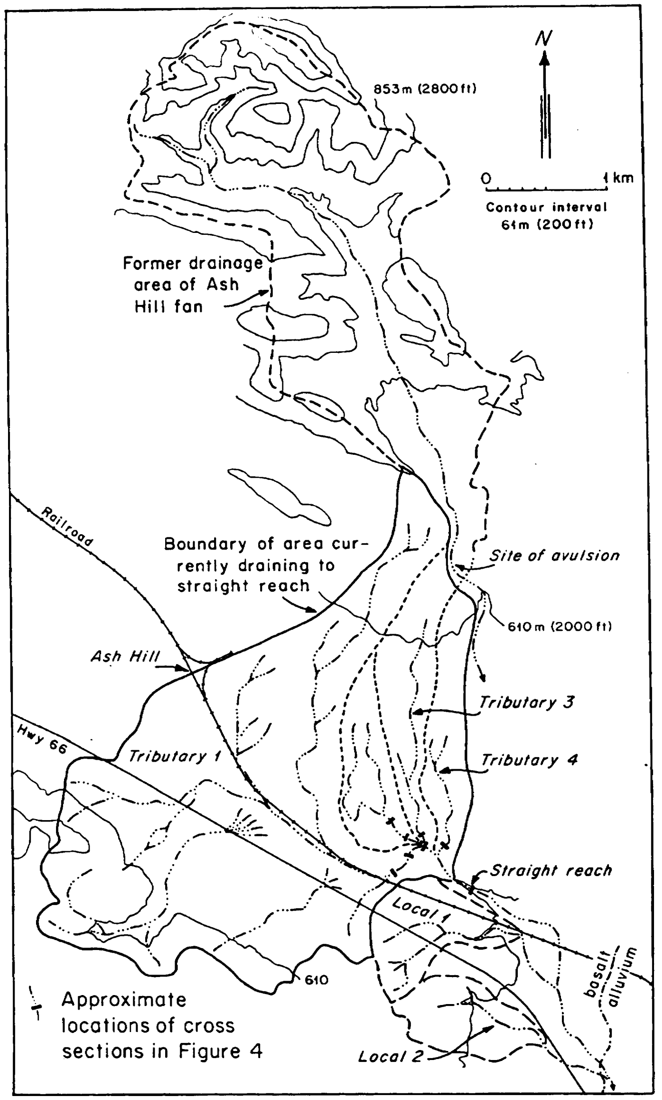

Figure 3. Map of part of Ash Hill fan and surrounding area. The head of Ash Hill fan is just above the site of avulsion; the toe is approximately along the railroad. The fan extends both to the east and to the northwest of the drainage divide shown by solid lines. The four tributaries to the Ash Hill channel and their present drainage areas (short dashed lines) are shown, as are two smaller drainage areas, Local 1 and Local 2, referred to in the text. Tributary 2 is not labelled; it lies between 1 and 3

al., 1957), upstream of the pass, contain sediments that would be consistent with a prolonged deep-water phase in the last 1 to 3 ma (Brown and Rosen, 1995, p. 289).

Hale undertook an intensive study of the Ash Hill channel, involving many weeks of fieldwork over some years, and presented intriguing arguments for his interpretation. In contrast, I have spent only about four days in the field there over a time span of about two years. However, I think my observations provide alternatives to Hale's interpretations, and may resolve the inconsistency between his conclusions and the lacustrine stratigraphy.

METHODS

In the field, I made observations of the character of geomorphic surfaces, including digging shallow holes to examine soils, and measured channel cross-sections using a 30 m tape and hand level. The fieldwork was

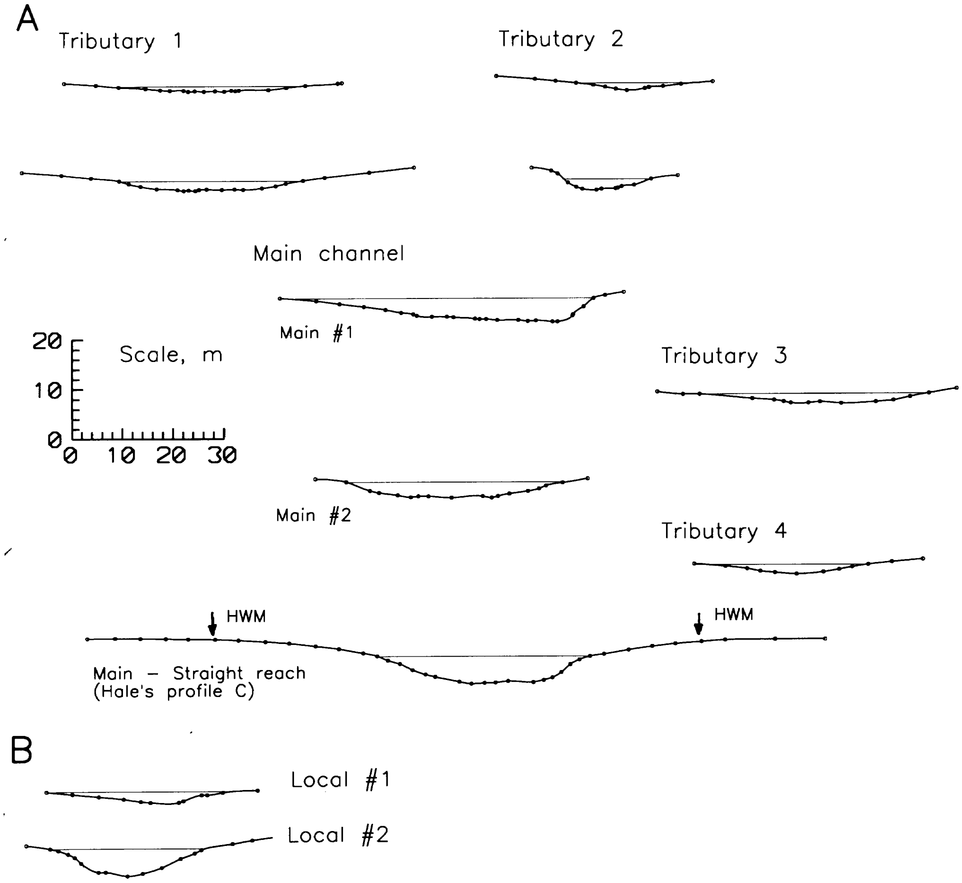

Figure 4. Profiles across channels. Horizontal lines were drawn between prominent inflection point(s) on the banks in order to define approximate cross-sectional areas of the channels. (A) Ash Hill channel and its four tributaries. The downstream profiles across Tributaries 1 and 2 and the profiles across Tributaries 3 and 4 were measured within 110 ± 20 m of their junctions with the main channel. HWM = positions of Hale's high water marks adjacent to channel in straight reach. (B) Channels in local drainages 1 and 2

focused on the area of the channel itself, but I also made traverses by car and on foot across the middle of the fan and to the fanhead to map channels and drainage divides, and to study evidence for the avulsion.

Drainage divides were mapped with the use of stereo air photographs in conjunction with 7½ minute topographic maps. Ambiguous localities were field checked. Areas were measured with a planimeter.

According to my measurements, the total area formerly draining to the Ash Hill channel is 16·2 km^2, whereas Hale reports an area of 18·4 km^2. In some locations, the position of the drainage divide is not obvious from topographic maps alone, and this may account for the discrepancy.

GEOMORPHIC SETTING

The reach of bedrock channel that Hale studied most carefully is referred to herein as the *straight* reach. The basalt flow (Dibblee, 1967) into which it is cut has been dated at 5·56 my (B. Turrin, unpublished data reported by Hale, 1985, p. 39). Fan gravels lap onto the basalt from north and south.

Traced upstream, the channel splits into four tributaries, all also cut in basalt and all roughly comparable in size, though smaller than the channel in the straight reach (Figures 3 and 4A). These tributaries, herein referred to as tributaries 1, 2, 3 and 4, presently collect water from Ash Hill fan and from surrounding upland drainage basins. The point where tributaries 1, 2 and 3 join is *c.* 2·4 km from and 35 m below the pass at 595 m. As noted by Hale (1985), bedrock outcrops in the banks and particularly in the beds of the tributaries clearly preclude the

possibility that there is a large buried (overflow-carrying) bedrock channel extending from the straight reach to the pass.

HALE'S EVIDENCE

The following are the principal lines of evidence that Hale (1985) uses to support the overflow hypothesis.

I. In *c*. 20 m wide bands on either side of the channel in the straight reach, cobbles and boulders are more numerous and more exposed than they are further from the channel. Hale believes that this change in surface character respresents a high water mark. On this basis, he calculates a discharge in excess of 2000 $m^3 s^{-1}$. This, he argues, is too high to be a result of runoff from a drainage area of *c*. 18 (or 16) km^2.

II. Hale compares the size of the channel in the straight reach with the size of 'the most recently active channel' on Ash Hill fan and finds that the former is significantly larger. He thus concludes that the straight reach is not a continuation of a channel on the fan.

III. Hale finds that channels on Ash Hill fan are significantly steeper (0·028) than the straight reach (0·015), and therefore believes that flows coursing down the fan and then diverted across the more gently sloping basalt would have been depositing, not eroding, as they crossed the basalt. Thus, the channel in the straight reach could not have been cut unless water also came from another source, namely overflow from Lake Manly.

IV. Also based on the above difference in slope, Hale suggests that, once the channel in the straight reach was cut, sediment transported through channels on the fan would have been deposited in it if it had not been kept free of such sediment by larger discharges from another source.

V. Hale argues that the lack of a well-defined connection between the channel in the straight reach and Ash Hill pass is consistent with other situations in which overflow from a lake crossed a volcanic tableland before incising a channel in a steeper area.

VI. In support of the existence of a lake at the 595 m level, Hale reports rounding of scattered pebbles below this elevation, but not above it, on a nearby volcanic hill, and also describes a number of lacustrine deposits at approximately this level in the area extending over 200 km northwards from Ash Hill to Death Valley.

DISCUSSION

In this discussion of Hale's evidence, I will not address point VI above, except to say that Hale himself acknowledges that alternative interpretations of all of the lacustrine deposits are possible. Rather, I will focus on the question of whether such a channel could have been eroded by locally derived runoff as Brown and Rosen (1995, p. 290) maintain. Let me first deal with the question of the features which Hale infers to be high water marks.

High water marks

As noted, Hale observed a transition in clast frequency and exposure that parallels the channel in the straight reach. He inferred that this transition was a high water mark from floods in the channel.

The surface further away from the channel is smooth, and cobbles and boulders in it are largely buried in tan sandy silt which, however, lacks any vesicular (Av) structure. Hale refers to this surface as a desert pavement, although the stones in it do not fit together in a tight mosaic as is found in well-developed pavements. This part of the surface slopes gently, in a direction parallel to the channel.

Within about 20 m of the bedrock bank of the channel, however, the surface slopes toward the channel and is convex upward as shown in the lowest of the cross-sections in Figure 4A. Here, cobbles and boulders are more numerous and project further above the surrounding ground surface (Figure 5).

Let us consider whether this transition could be a product of slope processes rather than a high water mark. The processes that must be considered are creep and splash erosion from raindrop impact (e.g. Carson and Kirkby, 1972, pp. 340–341). A third common slope process, slope wash, must be insignificant on the convex part of the profile as the drainage divide is effectively at the upper limit of the convexity.

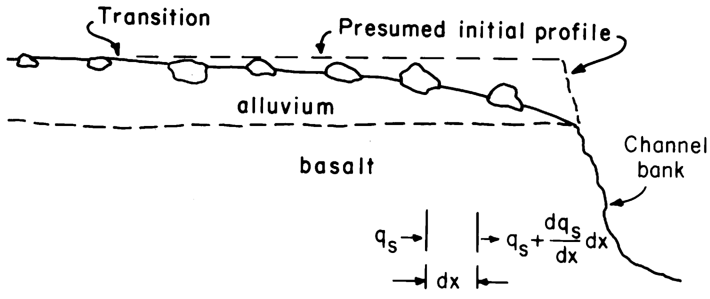

Figure 5. Sketch, based on field observations, of slope above bedrock channel in the straight reach. Not to scale. Profile crosses the transition which Hale inferred to be a high water mark. Note convexity of slope profile and increased frequency with which cobbles and boulders project above the surface below the transition

We wish to consider whether these slope processes could, through time, produce a slope of the observed character from some initial surface. Thus, we must first propose an appropriate initial condition. During early stages of incision of the bedrock channel, flows must have first cut down through the alluvium and then begun to attack the underlying basalt. If we may use the banks of modern washes on fans as a guide, the bank in the alluvium may have been nearly vertical initially (Figure 5). This would be true so long as the alluvium had had time to dry out and develop at least a slight cohesion after it was deposited.

With time, slope processes acting at the top of this bank would have moved finer material laterally into the channel, leaving coarser debris behind. The evolution of such a slope would be governed by the continuity relation:

$$\frac{\mathrm{d}q_s}{\mathrm{d}x} = -\lambda \frac{\mathrm{d}h}{\mathrm{d}t} \tag{1}$$

where $\mathrm{d}q_s/\mathrm{d}x$ is the change with distance, x, of the sediment flux, q_s toward the channel (Figure 5), and $\mathrm{d}h/\mathrm{d}t$ is the change with time, t, of the height of the ground surface, h, above an arbitrary datum. If more sediment is leaving a control area of size $\mathrm{d}x$ than is entering it ($\mathrm{d}q_s/\mathrm{d}x$ positive), the ground surface will be lowered ($\mathrm{d}h/\mathrm{d}t$ negative), and conversely. λ is a constant of proportionality that takes into consideration the difference in density between the sediment in motion and that in place in the slope. In both creep and splash erosion, $q_s \propto \mathrm{d}h/\mathrm{d}x$, the slope of the ground surface. Inserting this into Equation 1 leads to a diffusion-type equation. A solution to this equation, using a profile similar to the dashed profile in Figure 5 as an initial condition, has been obtained by Carslaw and Jaeger (1959, p. 104) and is discussed in a geomorphic context by Culling (1963). Briefly, the steep bank evolves into a convex slope as Gilbert (1909) recognized nearly a century ago. The increase in slope toward the channel provides the increase in sediment flux (positive $\mathrm{d}q_s/\mathrm{d}x$) required by the fact that the amount of sediment being moved toward the channel must increase as the distance from the channel decreases.

In summary, I would argue, the transition which Hale interpreted to be a high water mark is simply the present upper limit of a convex slope that is continuing to evolve by creep and rainsplash. The difference in character of the surface across that transition is a result of removal of finer particles from around cobbles and boulders, leaving the latter more exposed.

If my interpretation is correct, there is no reason to suppose that water ever actually filled the straight reach of the Ash Hill channel as Hale proposed.

Channels on alluvial fans

The main channel at the head of an alluvial fan is commonly incised. This channel typically merges with the fan surface in the mid-fan area, in what I have previously referred to as the *intersection point* (Hooke, 1967). Down-fan from this point, the flow spreads out in multiple distributaries.

When traced up-fan, the present tributaries to the bedrock channel at the toe of Ash Hill fan bifurcate and diminish in size (Figure 3). None of them is connected to such a distributary network on Ash Hill fan, and none

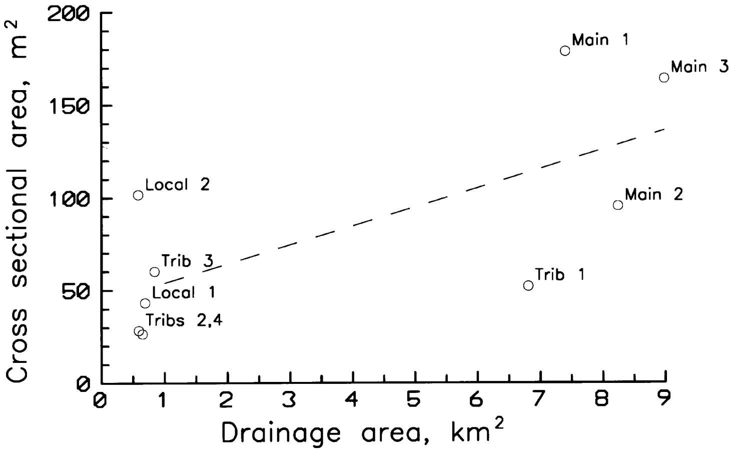

Figure 6. Relation between cross-sectional areas of channels, as defined in the caption to Figure 4, and the areas of the watersheds presently draining through those cross-sections. Main 3 is Hale's cross-section C in the straight reach. The poor correlation is presumed to reflect local inhomogeneities in the basalt that affect each channel cross-section differently

intersects the bank of the present fan-head channel in a depression that could be interpreted as being a remnant of a former fan-head channel. Thus, these tributaries appear to be channels that head on Ash Hill fan or, in the case of some of the drainage to Tributary 1, in small northward-draining watersheds to the south (Figure 3). With the exception of the latter, these tributaries carry runoff from rain falling directly onto the fan surface. They post-date the avulsion.

At the toe of a fan that grades into a playa, flow coursing down the fan spreads out across the playa surface. However, at its toe, Ash Hill fan butts against the toes of smaller fans built by the northward-draining watersheds. In such situations, flow that was distributed in several channels higher on the fan surface collects into a single channel again and flows laterally along the toes of the fans. In the case of Ash Hill fan, this fan-toe channel system coincides approximately with the railroad, and the bedrock channel is one part of it.

In my interpretation, the bedrock channel has always collected water, as it does today, from not one but several channels on Ash Hill fan, and from similar channels on the fans to the south. This was true before the avulsion, when the several channels were distributaries from the main channel at the fan head, as well as after the avulsion when the several channels were (and are now) draining separate areas of the fan surface. In this respect, I agree with Hale (point II): the bedrock channel is not a continuation of a *single* channel on the fan.

Because the fan-toe channel was collecting flow from a number of tributaries, it is likely that these combined flows would have been capable of cutting the bedrock channel, despite the lower slope across the basalt (Hale's argument III). This also explains how the bedrock channel has been kept free of sediment throughout its existence (Hale's argument IV). (Note that Hale's explanation for this observation would only apply to the time when overflow was presumed to have been occurring, and thus does not explain how the channel has been kept free of sediment subsequently.)

Headward migration of knickpoints

I will not contest Hale's argument (V) that overflow from a lake can occur in a distributed flow system for some distance before the water collects into a single channel. In fact, given that the basalt into which the bedrock channel is cut ends *c*. 1·5 km downstream from the end of the straight reach (Figure 3), it is likely that the channel was formed as a knickpoint, or a series of such knickpoints, migrated headward from the basalt/alluvium contact. An argument to the effect that an overflow might not have lasted long enough for the knickpoint to reach the pass is, thus, quite plausible.

Other observations, however, are less consistent with the overflow hypothesis. First, of the four tributaries, only Tributary 1 has a course that is consistent with the suggestion that it carried flow from the vicinity of the pass, and it becomes quite small only a short distance above its junction with Tributary 2 (Figure 4A). Its original character, however, is obscured owing to remodelling of the landscape during railroad construction.

Secondly, there are two imposing channels, Local 1 and Local 2, that drain across the basalt and join the main channel downstream from the straight reach (Figures 3 and 4B). The watersheds feeding these two channels are entirely within the low hills to the south of the straight reach, and could never have received any flow coming through Ash Hill pass. These channels are not as large as the main channel, but neither are the areas of the watersheds draining through them (Figure 6). They testify to the ability of local drainage from quite small watersheds to cut deep channels through the basalt, given enough time.

ORIGIN OF THE ASH HILL CHANNEL

The above arguments suggest that the Ash Hill channel was cut by water that, after coursing down the various alluvial fans in multiple channels, collected to form a single large flow in a fan-toe channel at the junction between Ash Hill fan and the fans deposited by flows from the south. The impressive depth of the channel in and somewhat upstream from the straight reach is a result of headward migration of multiple knickpoints, probably associated with layering in the basalt.

If this interpretation is correct, the Ash Hill channel cannot be cited as evidence for overflow of Lake Manly.

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